IMPACT OF HEARING AID USE ON VESTIBULO-OCULAR REFLEX AND BODY BALANCE

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CERTIFICATE

This is to certify that this dissertation entitled **"Impact of hearing aid use on Vestibulo-ocular reflex and body balance"** is a bonafide work submitted as a part for the fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: 15AUD009. This has been carried out under the guidance of the faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

May, 2017

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CERTIFICATE

This is to certify that this dissertation entitled **"Impact of hearing aid use on Vestibulo-ocular reflex and body balance"** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

May, 2017

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DECLARATION

This is to certify that this dissertation entitled **"Impact of hearing aid use on Vestibulo-ocular reflex and body balance"** is the result of my own study under the guidance of Dr. Niraj Kumar Singh, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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Abstract

Hearing impairment is the most frequent sensory deficit seen in adults all over the world. At present, hearing aids or cochlear implants are the only options for dealing with sensorineural hearing loss. However, maximum power out from the hearing aids can have an impact on vestibular system because these levels of sounds could cause undesirable vestibular stimulation, as has been shown through generation of vestibular evoked myogenic potentials by acoustic stimulation using high sound pressure levels. Therefore, the present study aimed at investigating the effect of hearing aid on vestibular system and body balance. Using time series research design, behavioural balance assessment and video head impulse tests were administered on 20 participants with bilateral sensorineural hearing loss. The experimental conditions included obtaining the responses in unaided, unilateral hearing aid and bilateral hearing aid conditions for two sound inputs of 60 dB SPL and 80 dB SPL. Presence of refixation saccades on vHIT and abnormal results on behavioural balance function tests was encountered in significantly higher proportion of individuals when using unilateral hearing aid than unaided or using bilateral hearing aids ($p < 0.05$). Further, moderately severe and severe degrees of hearing loss caused these results more often than moderate hearing loss ($p < 0.05$). Therefore, use of bilateral hearing aid is better suited to balance sustenance than unilateral aid use.

Key words: *Hearing aid, vestibular overstimulation, vHIT*

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Hearing loss is considered to be one of the leading health concerns around the world. According to World Health Organisation (WHO), there were 360 million (5.3% of the world's population) individuals in the world suffering from hearing loss by 2012. As per national sample survey organisation (NSSO, 2002), 63 million (6.3%) people suffer from significant hearing loss. The NSSO (2002) also found that hearing disability is the 2^{nd} most common disabilities and top most cause of sensory deficit in India.

Hearing loss leads to problems such as decreased perception of speech in noise, difficulty in understanding telephone conversations, music as well as environmental sounds. These difficulties can hamper the functioning of an individual in several ways, ranging from psychological to social life.

At present, hearing aids are the most common form of rehabilitation when hearing loss is an indication. Hearing aids fit over a wide range of hearing losses. The output of a hearing aid is dependent on the input level and gain of the hearing aids. For an appropriately fitted hearing aid, this output should be low enough to prevent the sounds being amplified to an uncomfortably loud level, yet high enough to improve the speech intelligibility and perception of sound quality for day-to-day conversation.

Need of the study

For an individual using hearing aid, the signal entering the hearing aid is not the same as the signal leaving the hearing aid; rather the signal leaving the hearing aid is modified considerably. Depending upon the class (mild, moderate, strong or extra strong), the output from a hearing aid could range from 90 dB SPL to 145 dB SPL. The exposure to such high levels could possibly produce vestibular excitation, as evidenced through the recordings of vestibular evoked myogenic potentials (VEMP), which can be clearly evoked by sound pressure levels ranging between 100-125 dB SPL (Singh & Barman, 2013).

The evidence for vestibular stimulation by loud sounds also comes from earlier investigations which reported a sudden shift or displacement in the visual field following stimulation at intensities of 115-130 dBSPL with pure tones that had rapid onset rates (Parker, Tubbs, Ritz, & Wood, 1968). These symptoms were thought to result directly from vestibular stimulation by loud acoustic stimuli (Parker et al., 1968). One of the mechanisms supporting this is based on the unidirectional flow of the perilymph and endolymph through labyrinth. Further proof of auditory sensitivity even at the level of semicircular canal (SCC) came from a study by Tseng and Young (2013) who reported abnormal caloric results in a number of individuals who were exposed to occupational noise, usually above 85-90 dBA. Since the output of a number of hearing aids is more than these values, there is a likelihood of abnormal SCC function induced by continuous use of these levels. Further, the excitation produced by the use of unilateral or bilateral hearing aids could produce vestibular stimulation, even for first time use.

Hence a vestibular examination should be done to assess the vestibular function in individuals fitted with hearing aids. This can be achieved using a new diagnostic tool called vHIT which is commercially available and capable of assessing individual SCC function (Halmagyi & Curthoys, 1988). It is a quick test of vestibular function that consists of monitoring eye movements as the patient fixates gaze on a target while the head is rotated to right or left unexpectedly using small amplitude high velocity and high acceleration head jerks. However, this aspect (effect of hearing aid use on vHIT response) has never been investigated previously.

Aim of the study

The aim of the present study was to investigate the effect of hearing aids on vestibular system and body balance.

Objectives of the study

In order to fulfil the above mentioned aim, the following objectives were taken up:

1. To study the effect of hearing aid use on outcomes of behavioural balance function tests in naive users of hearing aid.
2. To examine the effect of hearing aid use on vestibulo-ocular reflex beginning in the lateral, posterior and anterior semicircular canals in naive hearing aid users.
3. To study the association of degree of hearing loss with outcomes of behavioural balance test when using hearing aid in naive users of hearing aid.
4. To study the association of degree of hearing loss with outcomes of vHIT when using hearing aid in naive hearing aid users.

CHAPTER 2

REVIEW OF LITERATURE

Hearing aids are the sound amplifying devices designed for individuals with hearing impairment. They make the sounds louder and comfortable so that an individual with hearing impairment can hear both in quiet and noisy situations and participate fully in daily activities. They are classified into many types based on size, power and circuitry. The selection of hearing aids is based on the type and severity of hearing loss, listening needs, and lifestyle of an individual (National Institute on Deafness and Communication Disorders, 2013).

Maximum output (MPO) in a hearing aid refers to the highest sound pressure level that a hearing aid can generate. An optimum MPO is set considering the need to accurately deliver the processed sounds in its natural dynamic range and by providing comfort listening which can be ensured by setting a value below uncomfortable threshold. It can vary across type of hearing aid and severity of hearing loss ranging from 90 dB SPL to 135 dB SPL (Indian standards, 1984).

The prolonged exposure to high levels of sound (noise or music) can have an adverse effect on auditory system as well as vestibular system. Earlier investigations demonstrated that individuals exposed to loud sounds often experience balance disorders along with hearing loss (Oosterveld, Polman, & Schoonhey, 1982).

The saccular maculae are activated by the exposure to sound and neurons originating from saccule are particularly stimulated (Colebatch, Halmagyi & Skuse, 1994). Since auditory system and vestibular end organs have a common genesis, share common fluid environment because of a continuous common membranous labyrinth, same arterial blood supply and respond to sound (Baloh & Honrubia, 2002; Langman & Sadler, 2005; Hamid & Sheykholeslami, 2006; Eisen & Limb, 2007; Zaou, Kenna, Stevens, & Lecmali, 2009), loud sound exposure to auditory system could also have an effect on the vestibular system.

Vestibular evoked myogenic poptential (VEMP) is an important clinical tool used to assess the functions of the otolith organs and the vestibular nerve. The studies in the past on VEMP have shown that saccule can be stimulated with the sound levels of 90 dB or more (Welgampola & Colebatch 2009). In individuals exposed to loud sounds, they are constantly being stimulated by the level above 90 dB SPL and should therefore be susceptible to the deleterious effects of loud sound on vestibular end organs. Several researches have investigated the effects of occupational noise on vestibular responses and body balance.

Effect of loud noise exposure on body balance

In a retrospective study, Ogido, Coasta and Machado (2009) examined the medical records of 175 factory workers. They found that 13.2% of all records contained vertigo as one of the symptoms which was third most reported complaint after hearing loss and tinnitus. They further found a close association between duration of noise exposure and presence of vertigo.

In 2012, Raghunath, Suting and Maruthy administered a dizziness questionnaire to 20 factory workers who had a history of occupational noise exposure at least for a period of 10 years. The same questionnaire was administered to two control groups for comparison purposes-a group of 20 individuals who had similar physical activity to the workers but were not exposed to high noise levels and a group of 20 students who were never exposed to hazardous noise. The results showed that significantly higher number of factory workers had vestibular sysmptoms than the two control groups; however the symptoms were subtle.

More recently, Ballesteros, Pinto and Bolanos-Carriel (2016) administered dizziness questionnaire on 34 factory workers who had history of chronic noise exposure and compared the findings with 16 administrative staff who were working in the office and were not exposed to machinery noise often. They found more vestibular symptoms and more often in workers with chronic noise exposure history than administrative staff, showing that exposure to noise causes vestibular impairment.

Effect of loud noise exposure on otolith organs

Wang and Young (2007) investigated the effects of chronic noise exposure on vestibular evoked myogenic potentials. Twenty individuals with bilateral notched audiogram at 4 kHz were assessed using VEMP. 70% of the cases had abnormal VEMP. They also observed a direct association between the notches obtained in the audiogram and the results of VEMP.

Kumar and Bhatt (2010) examined the VEMP in thirty individuals with noise-induced hearing loss (NIHL). VEMP latencies were prolonged and peak to peak amplitude was reduced in NIHL subjects. VEMP was absent in 16 (29.0%) ears. The latency was prolonged and the peak to peak amplitude was reduced in 19 (34.6%) ears. VEMP results were normal in 20 (36.4%) ears. VEMP was abnormal or absent in 67% of

NIHL subjects. Hence they concluded that the possibility of vestibular dysfunction, specially the sacculocollic pathway, is high in individuals with NIHL.

Madappa and Mamtha (2009) evaluated the functioning and susceptibility of saccule on thirty individuals with NIHL using TEOAE and VEMP. The VEMP responses obtained were abnormal in 61.4% cases with a significant prolongation of P13 in 40% of ears and reduced amplitude of P13-N23 complex in 51.43%. TEOAEs had reduced amplitude with a response rate of 35.09%. The frequency of presence of VEMP response and reduced TEOAEs amplitude decreased with occurrence of varying degree of hearing loss.

Tseng and Young (2013) recorded cervical and ocular VEMPs (cVEMP & oVEMP) from 30 individuals with NIHL and 30 normal hearing subjects. The abnormal percentage of the test was 70% and 57% for cVEMP and oVEMP in NIHL subjects whereas 13 and 7% in normal subjects, respectively. There was a decreasing trend in the sequence of damage from cochlea, saccule, utricle and semicircular canals in NIHL. This supports that the pars inferior that is cochlea and saccule are more susceptible to noise than the pars superior which is the utricle and semi circular canals.

Chithra and Singh (2016) evaluated the effects of personal music system use on the saccule-colic reflex assessed by cVEMP. Thirty two regular music listeners and thirty two non regular music listeners were assessed using cVEMP. There were no significant differences in the latency and interaural asymmetry ratio but the amplitude was reduced in individuals in whom the diffused equivalent sound pressure level was above the damage risk criteria.

Effect of loud noise exposure on semicircular canals

Wang and Young (2007) investigated the effects of chronic noise exposure on semicircular canal response assessed using bithermal caloric test. Almost 70% of all workers had abnormally reduced caloric response in addition to abnormalities on cVEMP.

Tseng and Young (2013) carried out vestibular assessment in individuals exposed to occupational noise. They found that 33% of all the participants exposed to occupational noise had abnormally reduced caloric responses as against <5% of individuals who were not exposed to occupational noise. This was a significantly higher proportion, although semicircular canals were least affected among the vestibular structures.

From these evidences it is clear that noise as well as loud music has an impact on vestibular system and is dependent on the level and duration of noise/music exposure. These findings support the hypothesis that sound stimulation from hearing aids could also possibly stimulate and affect vestibular system.

Effect of hearing aid use on body balance

Rumalla, Karim and Hullar (2015) studied the relationship between audition and balance in older individual's using hearing aid. A total of 14 participants underwent balance assessment using Romberg test and tandem stance test. The tests were performed in the presence of point source white noise band in aided and unaided conditions. Results showed that the performance was significantly better in the aided than in the unaided condition. There was a significant improvement in the performance in aided condition than in unaided condition. However, the study used only bilateral hearing aid condition and assessments included were only subjective tests. Use of objective tests and comparisons between unilateral and bilateral hearing aids might have yielded a better understanding of the effect that hearing aid use has on body balance. However, no such study exists in the present literature.

CHAPTER 3

METHOD

Participants

Twenty participants in the age range of 15-50 years were selected for the study. The subjects included in the study had bilateral sensorineural hearing loss ranging from moderate to severe in degree and were fitted with bilateral hearing aid. However, they were naive users of hearing aid with no past experience with the hearing aid. Subjects with neurological disorder, psychological disorders, visual abnormalities, vestibular symptoms or obvious disorders of vestibular system were excluded. This was ensured through a detailed case history, cranial nerve examination and vestibular screening using sharpened Romberg, Fukuda stepping test, tandem stance test and past pointing test. Furthermore, individuals with other health related problems such as diabetes and hypertension were excluded from the study. The study also excluded individuals with middle ear pathologies. Informed written consent was obtained from all the participants and they were recruited to the study on a non-payment basis.

Test environment and instrumentation

All tests were carried out in well illuminated acoustically and electrically shielded rooms with ambient noise levels well within the permissible limits (ANSI S3.1, 1991). A calibrated dual channel audiometer Madsen Astera with TDH-39 headphones and B-71 bone vibrator was used to determine air- and bone-conduction thresholds respectively, of the participants. A calibrated immittance meter Grason-Stadler Incorporated- Tympstar was used to rule out the middle ear pathology. The commercially available video head impulse test system ICS impulse with monocular camera was used for obtaining VOR gain and identifying the presence of overt and covert refixation saccades. Fonix 7000 was used for the measurement of the sound pressure level in the ear canal with the appropriately fitted hearing aids. Cubase software was used for the presentation of the calibrated noise.

Procedure

Participants were fitted with bilateral digital hearing aids using NOAH software connected with HIPRO. Hearing aid was programmed using the NAL-NL1 prescriptive formula and subjective hearing aid evaluation was carried out using the standard speech material available in the subject’s native language. For this, the speech sounds were routed through the audiometer and presented at 40 dBHL (equivalent to 60 dB SPL). The appropriate fitting of the hearing aids was further ensured using subjective preference and insertion gain measurements. Further, the measurement of SPL in ear canal was accomplished for an input of 60 dB SPL in order to find out the SPL produced by the hearing aid in the ear canal in response to normal conversation level sounds. For this, the test stimulus was always a composite sound source produced by the system loudspeaker located at 45° azimuth and at a distance of 1 meter from the subject.

Levelling of the reference and probe microphones was done prior to the test session. The probe-tube was placed in such a way that it was approximately 5 mm off the tympanic membrane. Allowing the probe tube to extend at least 3 to 5 mm beyond the earmold tip ensured this. The signal was delivered at 60 dB SPL. This level was measured at the over-the-ear reference microphone position located just above the pinna of the test ear. The NAL-NL1 target gain formula was used in the verification stage as the standard against which the real ear insertion gain (REIG) values were obtained.

After ensuring the appropriate fitting of the hearing aids, the participants underwent detailed vestibular investigations using behavioural tests such as Romberg test, Fukuda stepping test and tandem stance test and objective test vHIT. All these tests were done in an acoustically treated room and starting point was in the centre of a circle of 2 m diameter. A total of 36 loudspeakers were placed along the circumference of this circle in such a way that the distance between loudspeakers was equispaced. The output for broadband noise measured when all loudspeakers were switched-on was calibrated to 60 dB SPL and 80 dB SPL in the presence of a manikin and clinician. In Romberg test, the subject was asked to stand with feet together, arms out stretched in front so that they were parallel to each other and to the ground and eyes closed. Presence of sway and its direction were noted. In Fukuda stepping testing, the subjects were asked to stand in the same position as Romberg test and march at a place with eyes closed. The deviation of > 45° in any direction and/or distance of >1m from starting point were deemed as abnormal result. For the tandem stance test, the subjects were asked to stand in tandem gait position (the toes of the back foot touching the heel of the front) for 30 seconds. Rising of arms or loss of balance before 30 seconds was deemed as an abnormal result. The time for which the subject maintained appropriate balance (up to maximum 30 seconds) was noted.

In the centre of the same circle, the participant was seated comfortably in a chair for vHIT testing. The monocular goggle was placed over the eyes and secured tightly using an elastic strap around the head. The test phase was preceded by calibration for which two laser points separated by 20° (10° on either side of a fixed dot present on the plank placed 1 meter in front at eye level) was projected on the wooden plank and the patient was instructed to look alternately at them. Once the calibration was accomplished, the patient was instructed to maintain gaze at the target dot on the plank and clinician made brief, unpredictable head rotations with a displacement of 10^o-$20^o$and peak head velocity of 100^o/s to 250^o/s. Twenty impulses were recorded specific to each side and plane. At the end of each head impulse the ratio of head and eye velocity provided the VOR gain. A mean gain value was obtained for 20 impulse recordings in each plane.

All the 6 semicircular canals were tested using ‘Lateral’, ‘LARP’ (left anterior right posterior) and ‘RALP’ (right anterior left posterior) modules of the ICS impulse vHIT system. For Lateral, the both palms of the clinician’s hands were positioned at the top of the participant’s head while ensuring no contact of her hand with the strap around the participant’s head that secured the goggle tightly. For RALP and LARP, head of the participant was rotated by 45^o to left and right respectively and head impulses were generated along the sagittal axis such that the middle finger of clinician’s hand on the top of the head was pointing at the target dot on the plank and head rotated forward or backward along its direction. For these two modules, one hand of the clinician was placed on the top of participant’s head while the other held his/her chin. Despite the head turn to left or right, the clinician’s top hand’s middle finger always pointed to the target dot straight in front. All the tests, both behavioural and vHIT were performed under three specific conditions- without hearing aid, with unilateral hearing aid and with bilateral hearing aid. Further, all tests were performed for sound levels 60 dB SPL and 80 dB SPL.

Testing sequence was randomized. Gaps were incorporated as and when required, usually after each module for a particular condition of testing (with & without hearing aid).

Response analyses

The responses were analysed using two major parameters - VOR gain and refixation saccades. The VOR gain was obtained directly from the software which produces the value upon dividing the eye velocity by the head velocity for each impulse in a particular direction and then averaging it to determine the average VOR gain for that direction of head movement. Refixation saccades were operationally defined to be present when a minimum of 50% of the traces for head jerks along any canal's plane contained overt or covert saccadic movement.

Research Design

The same individual was tested under three specific conditions. Hence the research design used in the study was time series design.

Statistical analyses

The obtained data points for various conditions and canals were subjected to Shapiro-Wilk's test of normality. The results revealed normal distribution of data. Therefore, parametric statistical procedures were carried out. Three-way repeated measures analysis of variance (three-way repeated measures ANOVA) was carried out for ears, hearing aid conditions and sound intensity for evaluating their effects on VOR gain. McNemar test was done for investigating the difference in proportion of individuals with abnormal results among hearing aid conditions (unaided, unilateral hearing aid use & bilateral hearing aid use). Further, for studying the association between degree of hearing loss and abnormal results on behavioural balance assessment tests or vHIT when using hearing aid, Chi-square test was done. In addition descriptive statistics was done to obtain mean and standard deviation. For all these analyses, statistical package for social sciences (SPSS) version 17.0 was used.

CHAPTER 4

RESULTS

In the present study, the aim was to investigate the effect of hearing aids on vestibular system and body balance. To achieve this, vHIT and behavioural balance assessment were administered on twenty individuals having bilateral sensorineural hearing loss and who were naive users of hearing aid. All these tests were performed done under three specific conditions - without hearing aid, with unilateral hearing aid and with bilateral hearing aid at sound inputs of 60 dB SPL and at 80 dB SPL. The outcome of each of the tests is described below.

Effect of hearing aid use on outcomes of behavioural balance function tests

The behavioural assessment of balance function included administration of Fukuda stepping test, Romberg test (classical) and tandem stance test. The data collected for tandem stance test was not considered for further analysis as there was error in the way in which the test was performed. It was meant to be a tandem stance test (subjected needed to stand with one foot in front of the other in a straight line at the centre point equidistant from each of the 36 loud speakers) whereas the test performed was tandem gait (walking heel-to-toe) and outside the circle of 36 loud speakers. Therefore, the data for this test was not analyzed and considered. The outcomes of Fukuda stepping test and Romberg test have been elaborated below.

Effect of hearing aid use on outcomes of Fukuda stepping test.

Fukuda stepping test was performed using the standard procedure enumerated by Fukuda which has been described in detail in the 'Method' section of the present study. The parameters noted were degree of deviation towards right / left side and distance travelled from the starting position. In case of >45^o deviation or >1 meter distance travelled from the starting position at the end of 50 steps, the result was deemed abnormal. Table 1 shows the number individuals showing abnormal results on Fukuda stepping test out of a total of 20 individuals with bilateral sensorineural hearing loss. It can be observed from Table 1 that use of hearing aid resulted in more abnormal results on Fukuda stepping test than unaided condition. Further, even within the aided condition there was discrepancy between unilateral and bilateral fitting conditions. There was higher percentage of abnormal results on Fukuda stepping test in unilateral hearing condition than bilateral. Furthermore, there was an increase in abnormal results with increase in sound level from 60 dB SPL to 80 dB SPL for unilateral as well as bilateral hearing aid conditions but no change in unaided condition.

Table 1.

Number and percentage of individuals with abnormal results on behavioural balance assessment

Test	Unaided at 60 dB SPL	Unaided at 80 dB SPL	UHA at 60 dB SPL	BHA at 60 dB SPL	UHA at 80 dB SPL	BHA at 80 dB SPL
FST	0 (0%)	0 (0%)	6 (30%)	3 (15%)	7 (35%)	5 (25%)
Romberg	0 (0%)	0 (0%)	5 (25%)	3 (15%)	7 (35%)	5 (25%)

Note: 'FST'- Fukuda stepping test; 'UHA'- unilateral hearing aid; 'BHA'- bilateral hearing aid.

McNemar test was done to compare bilateral and unilateral hearing conditions and the results revealed no significant difference in proportion of individuals with abnormal results on Fukuda stepping test for 60 dB SPL sound level [$\chi^2(1) = 8.23$, $p > 0.05$] or 80 dB SPL [$\chi^2(1) = 12.38$, $p > 0.05$]. McNemar test could not be used for comparison of unaided condition with unilateral or bilateral hearing aid conditions owing to lack of binomial representation of data in unaided condition; no one had abnormal result on Fukuda stepping test in unaided condition at any of the two sound levels.

Effect of hearing aid use on outcomes of Romberg test.

The classical Romberg test was performed. The results were deemed abnormal in case of presence of sway in any direction or inability to stand with eyes closed. Table 1 shows the outcomes of Romberg test in unaided as well as unilateral and bilateral hearing aid conditions for sound levels of 60 dB SPL and 80 dB SPL. It can be observed from Table 1 that abnormal results were more often encountered for aided condition than unaided. Further, abnormal results on Romberg test were observed in a higher percentage in unilateral than bilateral hearing aid condition. Furthermore, increase in sound intensity from 60 dB SPL to 80 dB SPL resulted in higher percentage of abnormal results for unilateral as well as bilateral hearing aid conditions; however there was no change in unaided condition. McNemar test was done to compare bilateral and unilateral hearing conditions and the results revealed no significant difference in proportion of individuals with abnormal results on Romberg test for 60 dB SPL sound level [$\chi2(1) = 3.26$, $p > 0.05$] or 80 dB SPL [$\chi2(1) = 12.38$, $p > 0.05$]. McNemar test could not be used for comparison of unaided condition with unilateral or bilateral hearing aid conditions owing to lack of binomial representation of data in unaided condition; no one had abnormal result on Romberg test in unaided condition at any of the two sound levels.

Effect of hearing aid use on outcomes of vHIT

All 20 participants underwent vHIT in the centre of the circle formed by 36 loud speakers. The test was performed in unaided condition as well as with unilateral hearing aid and bilateral hearing aid under the influence of 60 dB SPL and 80 dB SPL of white noise. Figure 1 shows representative vHIT recordings from one individual in the three hearing aid conditions and two sound levels. The measures obtained from vHIT recordings were presence of refixation saccades and VOR gain. The results pertaining to these two measures are described below.

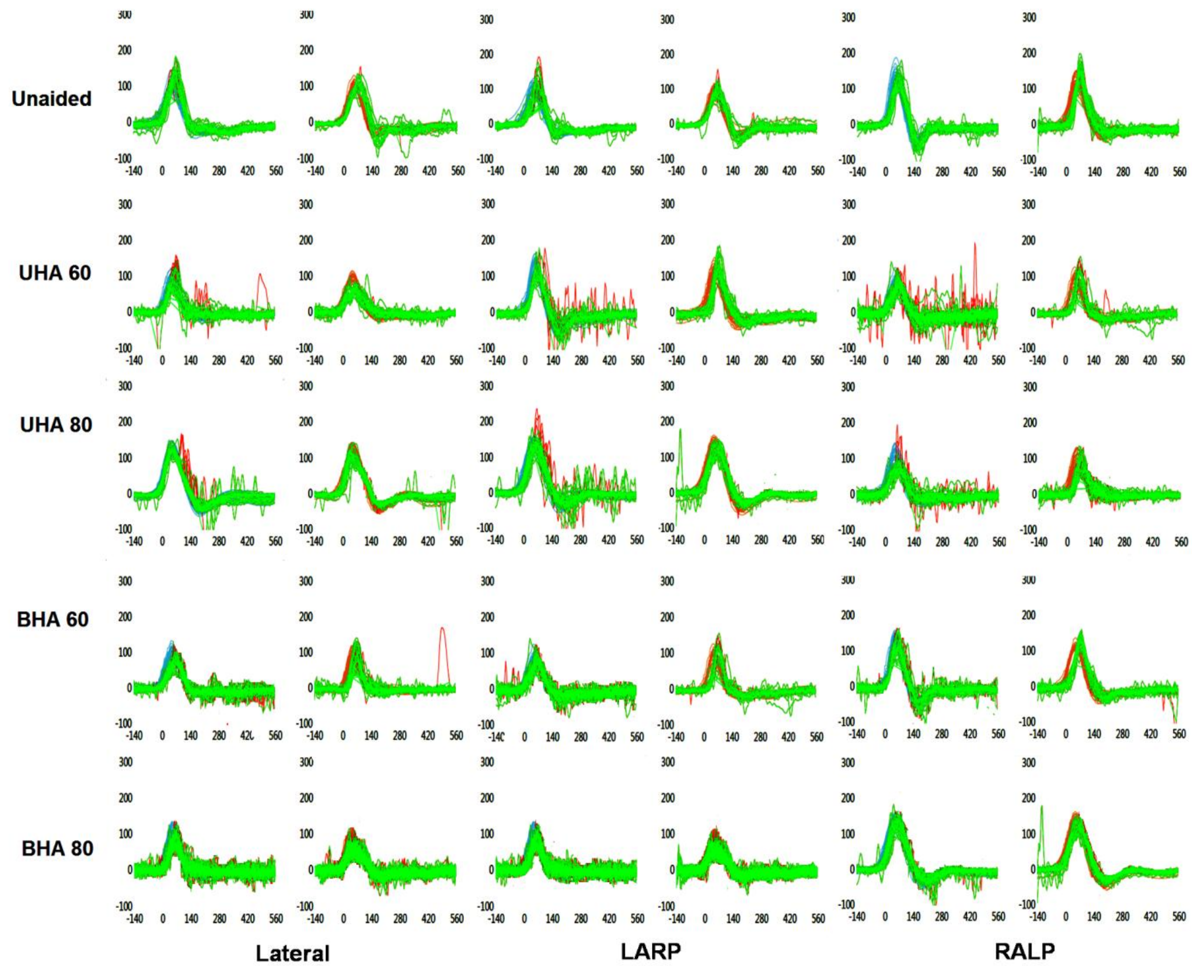

Figure 1: Representative vHIT recordings for unaided, unilateral hearing aid (UHA) and bilateral hearing aid (BHA) for 60 dB SPL and 80 dB SPL using lateral, LARP and RALP modules from an individual with bilateral symmetrical sensorineural hearing loss.

Effect of hearing aid use on VOR gain of vHIT.

In order to understand the effect of hearing aid conditions and sound level on VOR gain of vHIT, three-way repeated measures ANOVA was carried out for ears, hearing aid conditions and sound intensity. The results revealed significant main effect of ears on VOR gain of lateral canal [F(1,19) = 4.54, $p < 0.05$]; however there was no significant main effect of sound levels [F(1,19) = 0.41, $p > 0.05$] and hearing aid conditions [F (1,19) = 0.57, $p > 0.05$]. Further, there was no significant interaction between ears and sound levels [F(1,19) = 0.06, $p > 0.05$], ears and hearing aid conditions [F(1,19) = 0.37, $p > 0.05$], sound levels and hearing aid conditions [F(1,19) = 1.48, $p > 0.05$] and ears, hearing aid conditions and sound levels [F(1,19) = 1.40, $p > 0.05$]. Similarly for the anterior canals, there was a significant main effect of ears [F(1,19) = 19.728, $p < 0.05$] but no significant main effect of sound levels [F(1,19) = 0.41, $p > 0.05$] and hearing aid conditions [F(1,19) = 0.23, $p > 0.05$]. Further, there was no significant interaction between sound levels and ears [F(1,19) = 0.30, $p > 0.05$], hearing aid conditions and sound levels [F(1,19) = 0.29, $p > 0.05$], ears and hearing aid conditions [F(1,19) = 0.54, $p > 0.05$] and ears, hearing aid conditions and sound levels [F(1,19) = 1.41, $p > 0.05$]. Results of posterior canal showed significant main effect of ears [F(1,19) = 32.31, $p < 0.05$]; however there was no significant main effect of sound levels [F(1,19) = 3.40, $p > 0.05$] and hearing aid conditions [F(1,19) = 0.62, $p > 0.05$]. Furthermore, there was no significant interaction between sound levels and ears [F(1,19) = 0.78, $p > 0.05$], hearing aid conditions and sound levels [F(1,19) = 1.76, $p > 0.05$], ears and hearing aid conditions [F(1,19) = 1.27, $p > 0.05$] and ears, hearing aid conditions and sound levels [F(1,19) = 0.326, $p > 0.05$].

Effect of hearing aid use on presence of refixation saccades on vHIT.

Overt and/or covert saccades were operationally defined to be present only when a minimum of 50% of the head impulses in the plane of any particular semicircular canal contained saccadic movement. Table 2 shows the number and percentage of individuals who had refixation saccades in unaided, unilaterally aided and bilaterally aided conditions for 60 dB SPL and 80 dB SPL sound intensities for lateral, LARP and RALP modules of the vHIT system.

Table 2.

Number and percentage of individuals with presence of refixation saccades in unaided, unilateral hearing aid and bilateral hearing aid conditions for 60 dB SPL and 80 dB SPL sound intensities for lateral, LARP and RALP modules

Module	Sound intensity (in dB SPL)	Unaided		Unilateral hearing aid		Bilateral hearing aid	
		N	N (in %)	N	N (in %)	N	N (in %)
Lateral	60	2	10	8	40	2	10
	80	2	10	9	45	2	10
RALP	60	2	10	6	30	2	10
	80	2	10	9	45	2	10
LARP	60	2	10	8	40	2	10
	80	2	10	9	45	3	15

Note: ‘N’- number of individuals with presence of refixation saccades.

McNemar test was done for comparison of proportion of individuals with presence of refixation saccades between unaided, unilateral aided and bilateral aided at 60 dB SPL and 80 dB SPL for lateral, RALP and LARP modules. The results showed that significantly higher proportion of individuals had presence of refixation saccades in lateral module when wearing unilateral hearing aid than bilateral [$\chi^2(1)$

= 3.33, $p < 0.05$] and also when compared to unaided [$\chi^2(1) = 3.33$, $p < 0.05$] condition at 60 dB SPL. The comparison between unaided and bilateral aided revealed no significant difference in proportion of individuals with refixation saccades for sound intensity of 60 dB SPL [$\chi^2(1) = 20.00$, $p > 0.05$]. At 80 dB SPL sound intensity, the findings were similar to 60 dB SPL. Significantly higher proportion of individuals with unilateral hearing aid had refixation saccades compared to unaided condition [$\chi^2(1) = 3.33$, $p < 0.05$] as well as bilateral hearing aid condition [$\chi^2(1) = 3.33$, $p < 0.05$] whereas there was no significant difference between unaided and bilateral hearing aid conditions [$\chi^2(1) = 20.00$, $p > 0.05$].

For the RALP module, there was no significant difference in the proportion of individuals with refixation saccades between unaided and bilateral aided conditions for a 60 dB SPL sound intensity [$\chi^2(1) = 20.00$, $p > 0.05$]. However, unilateral aided condition resulted in significantly higher proportion of individuals showing refixation saccades than unaided [$\chi^2(1) = 5.18$, $p < 0.05$] and even bilateral aided condition [$\chi^2(1) = 5.18$, $p < 0.05$] at the same sound intensity. For the sound intensity of 80 dB SPL, similar results to 60 dB SPL were observed with significantly higher proportion of refixation saccades in unilateral aided than bilateral aided [$\chi^2(1) = 2.71$, $p < 0.05$] and unaided [$\chi^2(1) = 2.71$, $p < 0.05$] and no significant difference between bilateral aided and unaided [$\chi^2(1) = 20.00$, $p > 0.05$].

In case of LARP module, the results at 60 dBSPL showed that significantly higher proportion of individuals had presence of refixation saccades in lateral module when wearing unilateral hearing aid than bilateral [$\chi^2(1) = 3.33$, $p < 0.05$] and also when compared to unaided condition [$\chi^2(1) = 3.33$, $p < 0.05$] condition.

The comparison between unaided and bilateral aided conditions revealed no significant difference in proportion of individuals with refixation saccades at the same sound intensity [$\chi^2(1) = 20.00$, $p > 0.05$]. At 80 dB SPL, there was no significant difference in proportion of individuals with refixation saccades between unaided condition and bilateral aided condition [$\chi^2(1) = 20.00$, $p > 0.05$]. Nonetheless, unilateral use of hearing aid produced refixation saccades in significantly higher proportion of individuals than when no hearing aid was used [$\chi^2(1) = 3.33$, $p < 0.05$] or when bilateral hearing aid was used [$\chi^2(1) = 3.33$, $p < 0.05$]. Figure 2 shows comparison of individuals with refixation saccades between unaided, unilateral hearing aid and bilateral hearing aid conditions at 60 dB SPL and 80 dB SPL when using lateral, RALP and LARP modules.

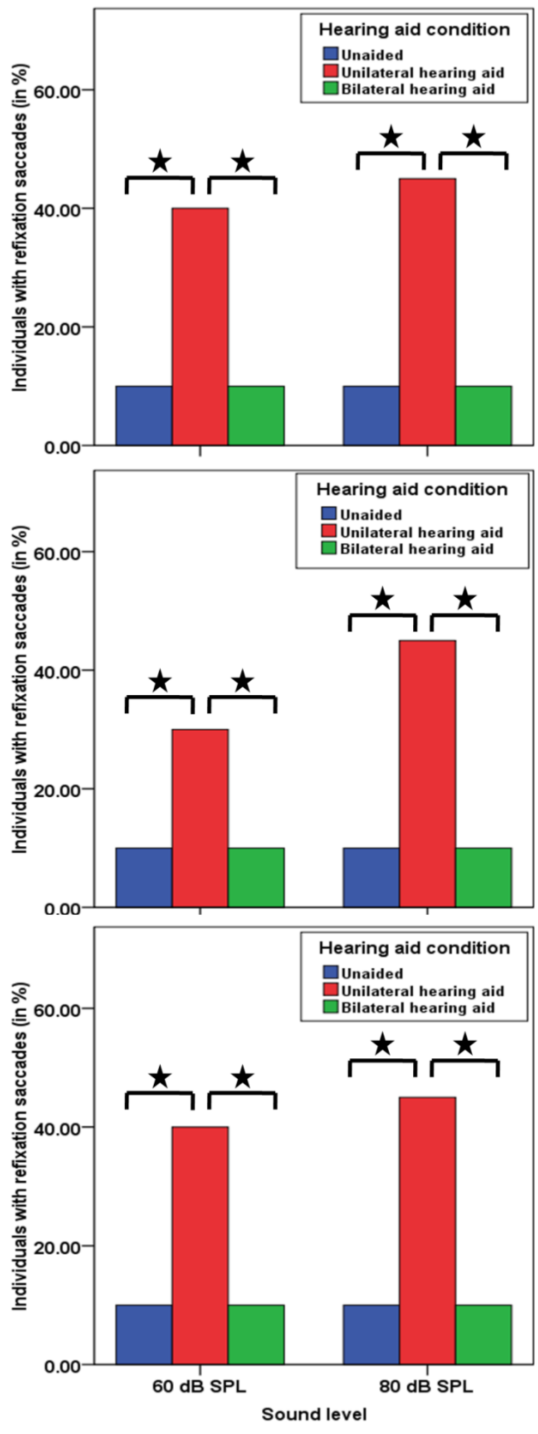

Figure 2: Percentage of individuals with refixation saccades between unaided, unilateral hearing aid and bilateral hearing aid conditions at 60 dB SPL and 80 dB SPL when using lateral (top panel), RALP (middle panel) and LARP (bottom panel) modules.

Association between degree of hearing loss and outcomes of behavioural balance function tests when wearing hearing aids

Present study had 20 participants with bilateral symmetrical sensorineural hearing loss, with degree ranging from moderate to severe. Of these, 11 participants had moderate hearing loss, 7 had moderately severe hearing loss whereas 2 had severe degree of hearing loss. Since the abnormal results were more often (larger 'N-value') associated with unilateral hearing aid use and there was no significant difference between unilateral and bilateral hearing aid conditions, the association using Chi-square test was studied only for unilateral hearing aid condition.

Abnormal results of Fukuda stepping test in aided conditions were seen in 4 and 2 individuals with moderately severe and severe hearing losses respectively when using 60 dB SPL sound through loud speakers. At this intensity, no one with a moderate degree of hearing loss showed abnormal results on Fukuda stepping test when using unilateral hearing aid. When the sound intensity was increased to 80 dB SPL, 5 and 2 individuals with moderately severe and severe degrees of hearing losses respectively had abnormal results whereas no one with moderate degree demonstrated abnormal findings. The statistical significance of association between presence of abnormal result on Fukuda stepping test when using unilateral hearing aid was evaluated using Chi-square test. The results revealed a statistically significant association between abnormal results on Fukuda stepping test and unilateral hearing aid use at 60 dB SPL [$\chi^2(2) = 11.83$, $p < 0.01$] as well as 80 dB SPL [$\chi^2(2) = 13.72$, $p < 0.01$] sound levels.

Abnormal results of Romberg test in aided conditions were seen in 3 and 2 individuals with moderately severe and severe hearing losses respectively when using 60 dB SPL sound through loud speakers. At this intensity, no one with a moderate degree of hearing loss showed abnormal results on Romberg test when using unilateral hearing aid. When the sound intensity was increased to 80 dB SPL, 5 and 2 individuals with moderately severe and severe degrees of hearing losses respectively had abnormal results whereas no one with moderate degree demonstrated abnormal findings. The statistical significance of association between presence of abnormal results on Romberg test when using hearing aids was evaluated using Chi-square test. The results revealed a significant association between abnormal results on Romberg test and unilateral hearing aid use at 60 dB SPL [$\chi^2(2) = 10.85$, $p < 0.01$] and 80 dB SPL [$\chi^2(2) = 13.72$, $p < 0.01$].

Association between degree of hearing loss and outcomes of vHIT when wearing hearing aids

Abnormal result on vHIT was observed only in terms of presence of refixation saccades but not for VOR gain. This (presence of refixation saccades) was more often seen with unilateral hearing aid use and there was no significant difference between unaided condition and bilateral hearing aid condition at both sound levels. Therefore, the association between degree of hearing loss and presence of refixation saccades was studied using Chi-square test only for unilateral hearing aid condition. Distribution of normal results (no refixation saccades) and abnormal results for the three modules (lateral, LARP, & RALP) at two sound levels (60 dB SPL & 80 dB SPL) is shown in Table 3.

Table 3.

Number of individuals (out of a total of 20) showing presence or absence of refixation saccades when using unilateral hearing aid on lateral, LARP and RALP modules at sound levels of 60 and 80 dB SPL

Module	Sound level (in dB SPL)	Refixation saccades	Degree of hearing loss		
			Moderate	Moderately severe	Severe
Lateral	60	Absent (normal)	10	2	0
		Present (abnormal)	1	5	2
	80	Absent (normal)	10	1	0
		Present (abnormal)	1	6	2
RALP	60	Absent (normal)	11	3	0
		Present (abnormal)	0	4	2
	80	Absent (normal)	10	6	0
		Present (abnormal)	1	1	2
LARP	60	Absent (normal)	10	2	0
		Present (abnormal)	1	5	2
	80	Absent (normal)	10	1	0
		Present (abnormal)	1	6	2

Note: ‘LARP’- left anterior right posterior; ‘RALP’- right anterior left posterior.

It can be observed from Table 3 that moderately severe and severe degrees of hearing losses were more often associated with presence of refixation saccades (abnormal results on vHIT) than moderate degrees when using unilateral hearing aid, irrespective of the canals being stimulated and sound levels. The statistical significance of this observation was investigated using Chi-square test. The results showed significant association between abnormal results on vHIT (presence of refixation saccades) and degree of hearing loss at 60 dB SPL sound level for lateral [$\chi^2(2) = 10.26$, $p < 0.01$], RALP [$\chi^2(2) = 11.83$, $p < 0.01$] and LARP [$\chi^2(2) = 10.26$, $p < 0.01$]. Similarly there was a significant association between abnormal results on vHIT and degree of hearing loss at 80 dB SPL sound level for lateral [$\chi^2(2) = 12.86$, $p < 0.01$], RALP [$\chi^2(2) = 12.86$, $p < 0.01$] and LARP [$\chi^2(2) = 12.86$, $p < 0.01$].

CHAPTER 5

DISCUSSION

The present study aimed at evaluating the effect of hearing aid on vestibular system and body balance. The outcomes in the present study were measured using parameters such as the VOR gain, refixation saccades obtained by vHIT and behavioural balance test on 20 individuals with bilateral symmetrical sensorineural hearing loss who were naive hearing aid users. Further, the association between degree of hearing loss and outcome of behavioural assessment and vHIT were investigated when wearing aid.

Effect of hearing aid use on outcomes of behavioural balance function tests

The behavioural balance assessment included the Fukuda stepping test and Romberg test. Hearing aid use resulted in more abnormal results on both these tests than unaided condition. In aided condition itself, there were more abnormal results in unilateral hearing aid condition than bilateral on both these tests. These findings were in disagreement to the findings of Rumalla et al (2015) who reported improved balance with hearing aid use than unaided condition among elderly adults with hearing loss. The discrepancy between the findings of Rumalla et al (2015) and the present study could be due to (1) use of bilateral hearing aid (2) population studied. In the present study unilateral as well as bilateral use of hearing conditions were evaluated and compared to unaided condition and found that unilateral hearing aid use resulted in more abnormal findings on Fukuda stepping test and Romberg test than bilateral hearing aid use and unaided condition. There was no significant change between unaided and bilateral hearing aid condition. Rumalla et al (2015) used only bilateral hearing aids and compared against unaided condition. It has been shown through studies on VEMP that vestibular system is stimulated when high sound levels, usually ≥75 dB nHL (100-110 dB SPL), are delivered to the ear (Colebatch et al., 1994). It has also been shown that hearing aids for people with higher degree of hearing loss could produce sound pressure in the ear canal that are on par with the levels that can stimulate the vestibular system. This suggests that unilateral hearing aid use would result in unilateral vestibular stimulation, thereby simulating the situation of unilateral vestibular impairment (stimulation on one side but no inhibition on the other). In such pathologies, Romberg and Fukuda stepping test results are abnormal (Bloem, Grimbergen, Cramer, Willemsen, & Zwinderman, 2001; Honaker, Boismier, Shepard, & Shepard, 2009). Since use of unilateral hearing aid produces resemblance with unilateral vestibular lesions, the results resemble too.

In case of bilateral hearing aid use, there is stimulation of vestibular system on both sides when wearing hearing aids. Since the hearing losses in all subjects were bilaterally symmetrical, the vestibular stimulation when using bilateral hearing loss would also be symmetrical. This ensured balanced stimulation on both sides and therefore did not increase the proportion of abnormal results on Fukuda stepping test and Romberg test compared to the unaided condition. Rumalla et al (2015) also used bilateral hearing aids and reported improved balance, probably because their subjects were elderly who already had imbalance (vestibular impairment) and use of bilateral hearing aid caused better stimulation of the two sides than unaided. In the present study, no one had vestibular hypo function or dysfunction and therefore such a scenario did not occur.

Effect of hearing aid use on outcomes of vHIT

Use of unilateral hearing aids produced refixation saccades in a significantly higher proportion of individuals than unaided or bilateral hearing aid condition. In the present study, use of unilateral or bilateral hearing loss would cause reduction or increase in differences in stimulation between the sides, depending upon unilateral or bilateral hearing aid use. This could become clear through the following example. In a normal individual, head impulse towards right produces depolarization in right sided lateral canal ampulla whereas inhibition is caused in the left sided one. Exactly opposite happens for direction of head impulse towards left side. This results in movement of the eyes in exactly opposite to the direction of head impulse (Baloh & Honrubia, 1979; Halmagyi & Curthoys, 1988). In case of hearing aid use on right side, there will be stimulation produced by sound energy vibrating the fluid on right side. When the head impulse is delivered in rightward direction, there is further increase in excitation (depolarization) in right ampulla and inhibition in left ampulla which increases the difference between excitation and inhibition, making it feel like a larger impulse than it is and resulting in overshooting eye movement and a following correction saccade. In case of left sided impulse, the excitation caused by hearing aid on right side will counter against inhibition, thereby reducing the effective difference. This would result in no saccades for this kind of movement. In case of bilateral hearing aid use, there would counter action produced to movement on one side in the opposite ampulla. The added excitation because of hearing aid on the same side will maintain the difference and therefore saccades would be produced on both side head impulses, which is what was observed in the present study. This can be further evidenced from the theory given by Von Bekesy, in 1935 that vestibular stimulation by sound did not occur when auditory stimuli were presented to both ears because the reflexes cancel each other. Thus, unilateral hearing aid will produce more saccades than unaided condition or when using bilateral hearing aid while doing vHIT.

The results revealed no significant difference in VOR gain between unaided, unilateral hearing aid and bilateral hearing aid conditions. An impaired VOR is usually as a result of an injury to the vestibular system or even due to systemic disease, migraine vestibulopathy, depression and aging (Furman, Redfern, & Jacob, 2006; Han, Song, & Kim, 2011). Individuals with vestibular impairment were ruled out in the present study. Hearing loss was the only condition present in them and hence their VOR gain remained unaffected under specific conditions.

Association between degree of hearing loss and outcome of vHIT and behavioural balance assessment when wearing hearing aids

Moderately severe and severe degrees of hearing losses were more often associated with abnormal results on behavioural balance assessment and presence of refixation saccades (abnormal results on vHIT) than moderate degrees when using unilateral hearing aid, irrespective of the canals being stimulated and sound levels. Use of unilateral hearing aid would have produced imbalance in degree of vestibular stimulation, as explained above. This is mainly because of the energy reaching the vestibular end organs. Higher degree of hearing losses require more output from the hearing aid thereby also resulting in more amount of energy reaching the vestibular system. This would cause increased difference in vestibular stimulation between the sides for higher degree of hearing loss than lower degree when wearing unilateral hearing aid, thereby producing more abnormality on behavioural balance assessment and producing more refixation saccades during vHIT.

SUMMARY AND CONCLUSION

Hearing loss is considered to be the third most chronic health condition among adults. Management of hearing loss varies depending on factors such as the severity of the hearing loss, type of hearing loss and their lifestyle. The management options available are surgical treatments or medicines for mainly conductive hearing losses and hearing aid for others.

The maximum power output of a hearing aid ranges from 90 dB SPL to 145 dB SPL, depending upon the class of the hearing aid. Exposure to such level stimulates the vestibular system, as evidenced by recording of VEMP for sound pressure levels ranging between 100-125 dB SPL (Singh & Barman, 2013). The exposure to such high levels could be potentially fatal for vestibular end organs, as shown by studies on the effects of occupational noise on vestibular system's responses (Kumar et al., 2010, Tseng & Young, 2013). However, a study exploring this aspect among users of hearing aid has not yet been reported. Hence, the present study aimed to investigate the effect of hearing aid on vestibular system and body balance.

In order to fulfil the aim, behavioural balance assessment and vHIT was performed on 20 individuals in the age range of 15-50 years who had bilateral symmetrical sensorineural hearing loss ranging from moderate to severe degree and who were newly (recently) fitted with bilateral hearing aids. After routine audiological evaluation, appropriate hearing aid fitting was verified by the standard speech material and insertion gain measurements. Validation measurements were also carried out where the measurement of SPL in ear canal was accomplished for an input of 60 dBSPL in order to find out the SPL produced by the hearing aid in the ear canal in response to normal conversation level sounds.

After the appropriate fitting of hearing aid, participants were subjected to the behavioural balance assessment tests which included Romberg test, Fukuda stepping test and tandem Stance test and objective test of balance assessment namely vHIT. All the tests were performed under three specific conditions - without hearing aid, with unilateral hearing aid and with bilateral hearing aid. Further all the tests were performed for sound levels 60 dB SPL and 80 dB SPL which were presented using 36 loudspeakers, equispaced around a circle of 2 meters diameter. The data for tandem stance test was later not considered for further analyses due technical deficits in the performance of this test.

The obtained data points for various conditions and canals were analysed using SPSS version 17.0. The effect of ears, hearing aid condition and sound level on VOR gain was analysed using Three-way repeated measures analysis of variance (three-way repeated measures ANOVA). McNemar test was done for investigating the difference in proportion of individuals with abnormal results among hearing aid conditions (unaided, unilateral hearing aid use, & bilateral hearing aid use). Further, for studying the association between degree of hearing loss and abnormal results on behavioural balance assessment tests or vHIT when using hearing aid, Chi-square test was done.

The results revealed significantly larger proportion of abnormal findings on behavioural tests in unilateral aided condition than unaided and bilateral aided conditions. It has been shown through studies on VEMP that vestibular system is stimulated when high sound levels, usually ≥75 dB nHL (100 – 110 dB SPL), are delivered to the ear

(Colebatch et al., 1994). This suggests that unilateral hearing aid use would result in unilateral vestibular stimulation, thereby simulating the situation of unilateral vestibular impairment (excitation on one side but no inhibition on the other) and hence abnormal results were obtained on these tests, as happens in cases of unilateral pathologies on these behavioural tests (Bloem et al., 2001; Honaker et al., 2009). In case of bilateral hearing aid use, there would be balanced stimulation on both sides and therefore there was no significant increase in the proportion of abnormal results on these tests in bilateral hearing aid condition when compared to unilateral condition.

The results of comparison of VOR gain between unaided, unilateral hearing aid and bilateral hearing aid conditions revealed no significant effect of the hearing aid conditions or sound levels because an impaired VOR is usually a result of an injury to the vestibular system or a systemic disease, migraine vestibulopathy, depression or aging (Furman, 2006; Kim et al., 2011). All these conditions were ruled out in the study and hence VOR gain remained unaffected under these specific hearing aids and sound level conditions.

In terms of the refixation saccades, significantly higher proportion of individuals in unilateral hearing aid condition had presence of refixation saccades than unaided or bilateral hearing aid condition. This is similar to the results of behavioural balance assessment and therefore the theory of unilateral excitation producing unilateral vestibulopathy like results also holds good here.

The study also found significant association between degree of hearing loss and abnormal results on behavioural tests and vHIT. This is because higher degree of hearing loss requires higher energy outputs from hearing aids which would cause increased stimulation of the vestibular system, thereby causing more asymmetric activation when using hearing aid unilaterally. Hence moderately severe and severe degrees of hearing losses were more often associated with abnormal results on behavioural balance assessment and presence of refixation saccades (abnormal results on vHIT) than moderate degrees in unilateral hearing condition.

Thus, it can be concluded from the findings of the present study that hearing aid use stimulates the vestibular system and in long run it could potentially damage the vestibular end organs. Further, unilateral hearing aid use is more detrimental than bilateral hearing use to body balance. Furthermore, lower degrees of hearing losses are spared from the detrimental impacts probably due to insufficient energy reaching the vestibular end organs.

Implication of the study

Findings of the present study show that use of hearing aid causes vestibular stimulation and imbalance when used unilaterally but not when used bilaterally. Therefore the inference from the present study suggests that this point could be an important inclusion when counselling for bilateral hearing aid fitting rather than unilateral. Further, higher degree of hearing losses are more often associated with vestibular overstimulation and potentially lead to vestibular impairment in the long run. So people with higher degree of hearing loss could be counselled regarding this and informed to start on a vestibular rehabilitation therapy program as part of their routine exercise to counter against this.

Limitation of the study

While the findings of the present study are promising, small sample size could produce reservations against generalization of the results. Further, the association between degree of hearing loss and abnormal results on behavioural balance assessment tests and vHIT is significant. However, these associations are based on a very small sample of subjects with higher degree of hearing loss, especially in the severe hearing loss category which had only 2 samples. Therefore, any strong recommendations cannot be made on the basis of these results. Furthermore, short term vestibular stimulation, although provides an insight, it does not necessarily guarantee the presence of vestibular disturbance in the long run.

Future directions

Present study showed promising results; however the sample size is a major limitation against generalization of the results of the population. Therefore future studies should use a larger subject sample that is equally divided between various degrees. Future studies might also benefit from using vestibular evoked myogenic potentials as dependent variable, as saccule and utricle are more susceptible to damaging effects of loud sound stimulation of the vestibular system. Also, use of experienced hearing aid users as another group could provide better insight in to the long term effects, about which the inferences are being drawn in the present study.

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